An experimental investigation of TiO_2 nanofluid as a base fluid for PV/T solar collector in low latitude tropical

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Abstract

Solar energy is a very potential and most abundant source energy available and it is free of cost in consuming this type of energy. Flat plate solar collector is a device that can convert solar radiation into the thermal energy and can be implemented to PV/T solar collector. In this study, a modified flat-plate PV/T solar collector was built by attaching the thermal collector underneath the PV collector surface. The application of nanofluid in PV/T solar collector as a heat-absorbing medium needs to be developed and characterized in different environments condition. The effect of nanofluid concentration on the thermal performance of the PV/T collector was investigated according to EN 12975-2 standard. The low volume fraction of the nanoparticles used in the present study were 0.3%, 0.6% and 0.9%, respectively. The efficiency of the system was compared to the water as a base fluid performed in low latitude tropical region (Bandarlampung climate). The experimental result shows that an increase of zero thermal efficiency up to 12% which is obtained by using nanofluid at the volume fraction of 0,9%.

Keywords: Solar, collector, PV/T, nanofluid, PV/T, tropical

1. Introduction

The sun is a renewable energy source that has several advantages such as being easily available, free of pollution and available in considerable quantities. A flat plate solar thermal collector is one of devices used to harness solar energy. This type collector is widely used to absorb solar radiation and convert it into heat energy which produce domestic hot water. In other applications, this type collector also can be implemented to absorb the excess heat collected on the surface of solar cell (Photovoltaic). In fact, every 1^0C increase in solar cell temperature causes electrical efficiency will decrease of about 0.45%. Therefore, the attaching the two surfaces between the thermal collectors and the solar cells is a good way to solve the problem. In particular, this type collector is also well known as a hybrid Photovoltaic/Thermal (PV/T) collector.

The PV/T collector can generate electricity and thermal energy simultaneously. Another advantage of using this type of collector is that the electrical efficiency remains stable even increases due to absorbing the excess heat by the working fluid on the surface temperature of the PV. Besides producing electricity, the PV/T collectors also produce hot working fluid so that they can be used for various purposes such as the heating process in industry and the health sector, household needs and other needs. Many studies have been carried out and reported over the last 25 years by several researchers those are related to the evaluation of thermal and electrical output[]. They present analytical and numerical models, simulation and experimental work, the development of performance testing processes.

1.1. Climate of Bandar Lampung

Climate has a significant influence on a building's performance, therefore the climate parameters need to be understood. Theclimate of Malaysia has the characteristics of a hot-humid tropical climate. It has been reported by Ref. [14] that Malaysia receives anannual total radiation of above 4.31kwh/m2, and about 10h of sunshine per a day. This causes a higher indoor temperature, whichneeds more energy for artificial cooling in order to succeed in providing thermal comfort in the workspace. The monthly sunshineduration ranging from 9 to 13 h, with a monthly average of solar radiation according to the data from Subang Jaya station variedfrom 4 to 4.6 kWh/m2. The highest monthly average was recorded in February and September with 4.52 and 4.6 kWh/m2respec-tively. The lower solar radiation occurs in December to January with 4 to 4.2kWh/m2respectively. Moreover, with respect to thesolar radiation on the building façade in Malaysia, Ref. [18] has reported that the maximum of solar radiation which faces verticalwalls would vary from 300 Wh/m2to 250 Wh/m2throughout the year. This increases the heat gain in indoor spaces particularly thespaces behind the fully glazed facades.In general, the climate of Malaysia can be described as typical tropical climate, with no large variations in temperature during themonths of the year. According to the data from the meteorological station of Subang Jaya (10 years), the mean monthly temperatureA.M. QahtanCase Studies in Thermal Engineering 14 (2019) 1004192

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was found to vary approximately not more than 1.4 °C difference, from the mean 27.0 °C in November to 28.4 °C in May as sum-marises inTable 1. The variation significantly occurs throughout the day with approximately 7.4 °C difference found between thedaytime and night-time in February and March and approximately 6.5 °C difference between the daytime and night-time in Novemberand December as summarises inTable 2.However, designing the energy efficient buildings (non-residential buildings) under the Malaysian climate are required to achievean acceptable indoor condition and conform the requirements of the Malaysian Standard, MS 1525: 2007, as summarised inTable 3.

1.2. Effect of Climate conditions on solar thermal performance

Characterization results of the solar thermal collector are also affected by the climate conditions where the collector are performed. Several studies reported the performance of solar thermal collector under different zone in the world. Sakhrieh and Al-Ghandoor [19] investigated experimentally the performance of five types of solar collectors under the climate conditions of Al-Zarqa, Jordan. The first four were flat plate (black coated selective copper, blue coated selective, copper collector and aluminum collector), while the last was evacuated tube collector. The average efficiency achieved for the evacuated tube collector was 0.76, while for the flat plate, it varied between 0.57 and 0.62.

Sabiha et al. [17] enhanced the performance of a heat pipe evacuated tube collector by using Single Walled Carbon Nanotubes (SWCNT) nanoparticles under climate conditions of Kuala Lumpur, Malaysia. In the case of water as heat transfer fluid, the highest efficiency was 54.37%, while for the new fluid it was 93.43% for the same flow rate of 0.025 kg/s.

Gill et al. [13] studied a heat pipe evacuated tube collector installed in an active system under northern maritime climate conditions (Dublin, Ireland). The annual efficiency of the considered collector was 82%. Also, efficiency values were higher in winter months.

Hassanien et al. [14] investigated the performance and the viability of using an evacuated tube solar collector to assist a heat pump for greenhouse heating in Kunming, China. The authors noticed that the average thermal efficiency of the evacuated tube collector ranged between 0.4-0.5 on sunny periods and 0.35-0.4 on cloudy periods. The annual thermal efficiency of the solar collector was 0.49.

Daghigh and Shafieian [15] evaluated theoretically and experimentally the performance of a solar water heating system with evacuated tube heat pipe collector. They presented graphically the daily collector energy intake and the effect of solar radiation. Also, the effect of environmental and functional conditions on thermal efficiency was explained.

1.3. Applications of Nanotechnology in PV/T Systems

2. Applications of Nanotechnology in PV/T Systems

Concerning to the PV/T solar collector, in fact, traditional working fluids (water or oil based fluids) used in the collector have low thermophysical properties in term of thermal conductivity and specific heat capacity. For this reason, nanofluid shall be alternatively applied to this type collector in enhancing the performance of the collector. In this context, Choi introduced nanofluid that contain a small quantity of nanoparticles which have diameter usually less than 100 nm [4-10]. It is mixed with conventional fluids providing more heat transfer ability. The solid particle dispersed in base fluid such as water, refrigerant, ethylene glycol, or thermal oils [6, 7, 10]. This could be important because by using nanofluid, the heat transfer through the fluid can be increased as well as the thermal performance of the whole system significantly [11].

Due to the benefits of using nanofluids in comparison with traditional working fluids, various researchers have carried out several studies to implement nanotechnology in PV/T Systems. Nanoparticles can be silicon carbide (SiC) and metal oxides (SiO_2, Al_2O_3, TiO_2, ZnO, Fe_3O_4, and CuO) which allow the extraction of excess heat on the surface of PV. Moreover, decreasing the temperature of PV surface leads to higher electricity generation.

Several researchers have obtained significant findings when metal oxide nanoparticles mixed with different base fluids as nanofluids. Sardarabadi and Passandideh-Fard [39] examined a numerical and experimental study of a photovoltaic thermal system used different types of nanoparticles. Nanofluids flow through copper tubes attached at the back of the PV surface. The type of nanoparticles used in this study were Al_2O_3, TiO_2 and ZnO. The results showed that TiO_2-water and ZnO-water gave the higher electrical efficiency than Al_2O_3-water. Regarding the thermal efficiency, ZnO/water exhibited significant values if compared with the two other types. In addition, they studied the effect of increasing the mass fraction of ZnO from 0.05 to 10% by weight. While the thermal efficiency increased by four times, the temperature reduced by only 2% and the electrical efficiency by 0.02%.

Hashim et al. [41] conducted an experimental investigation of the effect of using Al_2O_3-water as a cooling medium for the PVT system by applying forced convection. Different concentrations of AL_2O_3-water were applied (0.1, 0.2, 0.3, 0.4 and 0.5%).The authors concluded that at a concentration of 0.3%, the temperature dropped significantly to 42.2°Cand the electrical efficiency rose to 12.1%. On the other hand, increasing the concentration ratio higher than this value caused raising the temperature again to 52.2°C while the electrical efficiency declined to 11.3%.

Rejeb et al. [43] introduced the experimental and numerical studies of a PVT system cooled by several types of nanofluids. The authors tested different types of nanoparticles (AL_2O_3 and Cu) at several concentrations (0.1, 0.2, and 0.4wt%) with different base fluids (water and ethylene glycol) on the electrical and thermal efficiencies of the system. The results confirmed that the performance (thermal and electrical efficiencies) of water as a base fluid is more effective than ethylene glycol. The numerical model was used to predict the annual electricity production for three different cities: Lyon (France), Mashhad (Iran), and Monastir (Tunisia). In addition,Cu/water showed higher electricity output for the three different cities reaching 791kWhr/m2 in Monastir.

Nada et al. [44] presented an experimental study using AL_2O_3 nanoparticles dnm=20nm with Rt55 paraffin wax for enhancing the efficiency of a photovoltaic system. The authors built three modules: the first one was the reference module, a PCM layer was integrated into the back side of the PV for the second configuration, and in the third one

PCM layer with nanoparticles was used. All of the modules were tested under Egyptian climatic conditions from 8AM to 6PM. A mechanical stirrer was used to mix the PCM with 2%of the nanoparticles. The findings showed that by using the PCM and nanoparticles, the efficiency improved by 13.2% and the temperature declined by 10.6°C while, in the case of using the PCM only, the efficiency boosted by 5.7% and the temperature decreased by 8.1% only.

Sardarabadi et al. [45] conducted an experimental study on the effect of using SiO_2/water as a coolant in a PVT system. The mass fractions used were 1 and 3% by weight. The overall efficiency rose by 3.6 and about 7.9% for cases 1 and 3wt%, respectively, if compared with using pure water only. In addition, the highest increase in both thermal and exergetic efficiency was observed at 3wt% (12.8 and 24.31%, respectively).

Michael and Iniyan [46] carried out an experimental study by adding a thin copper sheet instead of a Tedlar layer to the silicon cell and used CuO/water as a cooling medium to enhance the performance of the system. The nanofluid was at 0.05% volume fraction. The authors tested the electrical and thermal efficiencies of the system with and without glazing. They found that the thermal efficiency when using glazing and nanofluid was enhanced by about 45% in comparison with water only, while the electrical efficiency reduced by roughly3%.Theauthors attributed this reduction to the need for a new heat exchanger with higher effectiveness.

Ghadiri et al. [47] introduced an experimental study of cooling a PVT system by using a ferrofluid Fe_3O_4 −water. The authors studied the effect of different mass concentrations 1and3wt% as well as changing the solar radiation

600and1100w/m2 on the overall efficiency and exergy rate. In addition, the performance of the ferrofluid was investigated under constant and magnetic field. The findings confirmed that ferrofluid enhanced the overall efficiency by about 76% at 3wt% if compared with using distilled water only. On the other hand, this value can be improved by 3% and the exergy rate by about 46% if the system is accompanied by an alternating magnetic field of 50Hz..

3. Experimental Procedures

3.1. Tables

The two different absorber material types of the collectors as presented in Figure 1 were tested indoors using a solar simulator based on European Standar EN 12975 (2006). According to this standard for indoors testing, the collector must be tested under incident radiation more than 700 W/m^2. Data collection were made for inlet and outlet fluid temperatures, ambient temperature and incident radiation, respectively. Then, all the temperature data and radiation data were measured using K-type Thermocouples with TM 947SD Thermometer and a Solar Power Meter SPM 1116SD, respectively. The mass flow rate of the working fluid was regulated by using a valve at a constant flow rate of 0.02 kg/m^2s as ssociated with EN 12975. The mass flow rate was applied constant for all the measurement tests performed in the current work. To vary inlet fluid temperatures during the test, electrical heaters were used. All measurement data were recorded every 10 seconds., as shown in Table 1.

The collectors utilized in this work are shown in Figure 1. It shows the external part of the two solar water heating systems, which are installed in the premises of the Department of Energy, Faculty of Mechanical Engineering, Polytechnic University of Tirana – Albania. Tirana is the capital of Albania and is situated in the central part of the country. The average altitude of the city is 110 m above the sea level and the geographical coordinates are 41.33 °N and 19.82 °E. The selected town has a typical Mediterranean climate and it falls at "Cs" group according to Köppen climate classification. It is characterized as hot and dry summers and mild and rainy winters [22]. Annual average number of sunny hours is = 2,500 h/year [23].

Flat-plate solar collectors used in this work are of selective type and were produced by Isofoton (Spain). A liquid heating flat-plate solar collector consists of the solar energy-absorbing surface, header and riser pipes, transparent cover, and the back insulation. The flux of incident radiation heats the absorbing surface and transfers it to a heat transfer fluid [24]. The evacuated tube collector is with heat pipe and was produced by Augusta Solar GmbH (Germany). A heat pipe evacuated tube collector consists of a heat pipe inside the vacuum sealed tube, containing a temperature sensitive medium. There are condensation and evaporation sections in the heat pipe. Solar radiation heats up and vaporizes the heat pipe fluid in the evaporation section, and the vapour then rises to the condenser where the vapour emits the heat and is condensed back. The heat transfer fluid flowing through a manifold absorbs the emitted heat. The condensed fluid flows back to the bottom of the heat pipe where the solar radiation begins heating it up again. To work properly, the heat pipes must have a minimum tilt angle in order for vapour to rise and the fluid to flow back [25]

The specific heat capacity and density of the prepared nanofluid can be calculated from water and nanoparticle characteristics at the bulk temperature by using the given equations of Xuan and Roetzel [13].

$Cpnf =$

$\varphi(\rho Cp)np+(1-\varphi)(\rho Cp)bf \; \rho nf$

, (1)

and

$\rho nf = \varphi \rho np + (1-\varphi)\rho bf.$ (2)

The efficiency analysis of PV/T system was evaluated from thermal and electrical efficiencies. The rate of heat transfer from the thermal solar collector was based on measuring the temperature of fluid flow in and out. The overall efficiency can be calculated from the total of thermal efficiency and electrical efficiency, known as the PV/T efficiency [14] [15].

$\eta pvt = \eta th + \eta el,$

3.2. Figures

Figures should be submitted with a resolution of minimum 300 dots per inch and followed by a figure caption, justified as block, as can be seen in Fig.1. Please make sure that the axes and any text within the figure are legible with a minimum font size of 8.

3.3 Equations

Equations should be arranged to the left, with characters similar to that of the body text and should be numbered.

$$q_u = F^{'}[(\tau\alpha)_{\acute{e}}G - U_L(T_m - T_a)] \quad (1)$$

$$q_u = \dot{m}c_p(T_m - T_a)/A_c \quad (2)$$

A simple model is developed in the current work based on the energy balance for the useful heat power per unit area. The Hottel-Whillier-Bliss equation (Dufie et al. 2006) given in Equation (2) is then modified to a dynamic model by including the heat thermal capacity term as the following (3): where $F^{'}(\tau\alpha)_{\acute{e}}$ is the zero loss efficiency, $F^{'}U_L$ is the overall heat loss coefficient, and $(mc)_{\acute{e}}$ is the effective thermal capacity respectively. In this case, the whole mass of the collector (the tube, absorber plate, cover and insulation) are represented by a single temperature that refers to the mean temperature of the working fluid. From the above equation, the q_u as the useful heat power per unit area is determined by the following equation: In equation (4), $\dot{m}$ is the mass flow rate of fluid, $c_p$is the heat capacity of fluid, $(T_m - T_a)$ is the temperature difference between mean fluid and ambient, and A_c is the area of absorber plate.

3.4 Lists

- Bulleted lists can be used to arrange information more clearly in the text.
- This type of bulleted are recommended.

4. Result and Discussion

Several thermal performance tests were conducted associated with different absorber materials and the same diameter of riser and header tubes. The solar thermal parameters as shown in Table 1 are zero loss efficiency $F'(\tau\alpha)_e$ and heat loss $F'U_L$ respectively most important result from your work can be explained here, as response to the research objectives. In this study, the effect of mass-flow rate and solar-radiation levels on the performance of PV/T system were obtained. Two types of working fluid were used, namely, distilled water and different concentrations of TiO2/water. The radiation changed from 700 W/m2 to 900 W/m2. The experimental results for the variation of temperatures (ambient, inlet, outlet, and PV) under different mass flow rates

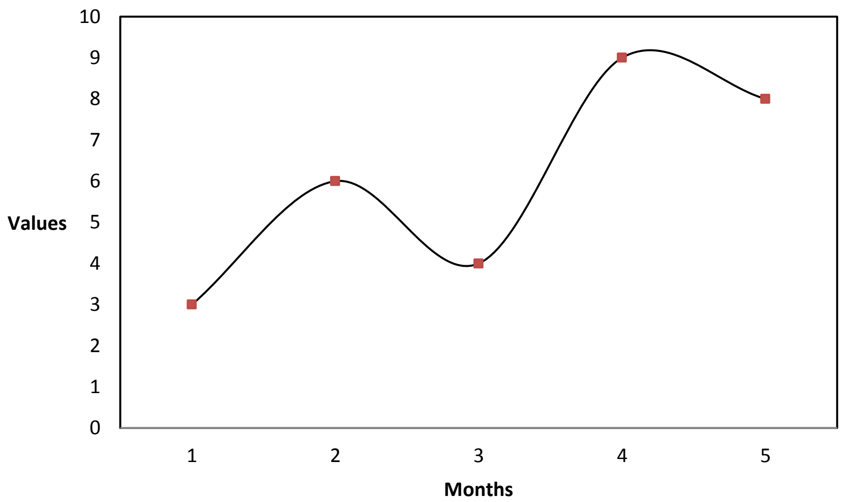

Fig. 1: Figure captions (8 pt) should be justified as block and placed below the figure

Figure 2 presents variation of thermal efficiency against reduced temperature parameter ($T_{red} = \frac{(T_m - T_a)}{G}$) for different absorber materials. From Figure 2, it describes the effect of two absorber materials on thermal efficiency of solar collector. As shown in the Figure 2, it presents that at zero reduced temperature, the thermal efficiency levels of the solar collector is 46.7% for copper and 37.1 % for aluminum, respectively. Therefore, the copper as an absorber material has better thermal performance than the aluminum material. However, increasing the value of zero loss efficiency $F'(\tau\alpha)_e$ for copper is only 9.6 % compared to that of the aluminum material. This means that the copper material does not significantly increase the thermal efficiency of the solar collector in comparison with its thermal conductivity value. Meanwhile, heat losses $F'U_L$ parameters of the two materials are nearly the same as given in the Table 1.

Table 1: Table captions (8 pt) should be justified as block and placed above the table

Month		**Ambient Temp. (° C)**	**Cell Temp. (° C)**	
January		26	30	

Variasi Temperatur / **Variasi Fluida**		**Inlet Fluid Temperature**			
		27^0C	32^0C	37^0C	42^0C
Water	ΔT (^{0}C)	8,4	7,4	6,3	5,2
	Efisiensi	0,48	0,42	0,36	0,30
NF TiO_2 (0,3%)	ΔT (^{0}C)	9,0	8,1	7,0	6,0
	Efisiensi	0,52	0,46	0,4	0,35
NF TiO_2 (0,6%)	ΔT (^{0}C)	10,3	9,5	8,4	7,3
NF TiO_2 (0,9%)	ΔT (^{0}C)	11,4	10,7	9,6	8,4
	Efisiensi	0,64	0,60	0,54	0,47

Meanwhile, the experimental results were compared with those obtained by Ekremian et al. (2015) associated with conventional solar collector. There is a significant different between the thermal efficiency obtained from the two results. The zero loss efficiency (at zero reduced temperature) of the conventional solar collector is 80 % for copper material which is 33% higher than that of the present study. This may be affected by using the same diameter of header and risers, therefore the dwell time of the fluid circulation will be shorter than that of the conventional collector. Consequently, the working fluid also absorb the heat shorter than that of the conventional collector with the bigger header tubes.

Table 1 presents comparison between the two materials based on price and thermal performance of the solar collector. Concerning the the absorber material, the price of copper is higher 14 times than the price of aluminum material. While, the difference of the thermal performance between the two material is only 10 %. Again, the price of materials is not proportional to increasing the thermal performance of the collectors. For this reason, the use of aluminum material as an absorber for solar thermal collector should decrease the material cost.

5. Nomenclature

A	collector efficiency factor	m^2
x	radiation	m
	temperature	C
$\dot{m}$	mass flow rate	kg/s
	energy gain	
	thermal conductivity	W/mC
	heat specific of fluid	J/kgC
U_L	overall heat loss coefficient	W/m^2C
	area	m^2

Greek letters

α	heat transfer coefficient	$Wm^{-2}K^{-1}$
τ	residence time	s

Subscripts

i	inlet
e	equilibrium

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